Atty. Docket No. 2590P071
Express Mail Label No. EV387144746US

UNITED STATES PATENT APPLICATION

FOR

METHODS OF CONTROLLING A CAMLESS ENGINE TO PREVENT INTERFERENCE BETWEEN VALVES AND PISTONS

INVENTORS:
Guy Robert Babbitt
Christopher Stevens Balton

PREPARED BY:
BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN LLP
12400 Wilshire Boulevard
Seventh Floor
Los Angeles, California 90025
(714) 557-3800

2590P071

METHODS OF CONTROLLING A CAMLESS ENGINE TO PREVENT INTERFERENCE BETWEEN VALVES AND PISTONS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 60/463,468 filed April 17, 2003.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of camless engine valve actuation for internal combustion engines.

2. Prior Art

An interference engine is an internal combustion engine in which the intake or exhaust valve or valves, or both intake and exhaust valves may at different times occupy the same space as the respective piston, or the same space as each other. In a properly operating camshaft driven valve operating system, the cam shape and camshaft timing automatically guarantee that the valves, and valves and piston, do not try to occupy the same space at the same time. In an interference engine equipped with an electro-hydraulic valve actuation system or any means of opening the engine valves that does not automatically mechanically prevent such interference, it is possible for a valve and piston to

collide, or valves to collide, usually with catastrophic results.

U.S. Patent No. 6,092,495 discloses a method of controlling electronically controlled valves to prevent interference between the valves and a piston. The method includes the steps of sensing position of the crankshaft during a number of engine cycles and generating a frequency signal in response thereto and calculating a crankshaft speed and a crankshaft acceleration based on the frequency signal. The method further includes the step of calculating a future piston position based on the crankshaft speed and the crankshaft acceleration. The method still further includes the steps of calculating a future engine valve position and comparing the future piston position to the future engine valve position to determine if the future engine valve position interferes with the future piston position. The method yet further includes the step of moving the engine valve to the closed position in response to determining that the future engine valve position interferes with the future piston position. An engine assembly is also disclosed.

The step of calculating a future piston position based on the crankshaft speed and the crankshaft acceleration and the step of calculating a future engine valve position are relatively complicated and processing intensive. The present

invention comprises simplified methods for controlling engine valves in such systems to minimize the likelihood that such an interference condition will ever exist.

The preferred embodiments of the present invention pertain to the control system for the Sturman HVA4 camless system, though are applicable to other camless systems as well. The Sturman HVA4 System is described in U.S. Patent Application Publication No. US 2003/0015155 A1, the disclosure of which is incorporated herein by reference. That application discloses a closed loop system wherein the position of the valves is known at all times and controlled by the feedback loop. Use of magnetically latching control valves is discretionary and not an essential part of that invention. Also that system is a two stage control system, with electronically controlled valves controlling a hydraulically controlled valve controlling the engine valve, though the present invention is not limited to such two stage systems, and may be used with other systems such as single stage hydraulic valve actuation systems and camless systems using other valve actuation technologies, such as, by way of example, electromagnetic, piezoelectric and pneumatic. In that regard, a camless engine as used herein means an internal combustion engine wherein the motion of one or more engine valves is not directly prescribed by the shape and timing of a cam valve actuation system.

In accordance with that disclosure, one embodiment of such a system is shown in Figure 1. The controller 33 controls electrically operated vent pilot control valve 20 and supply pilot control valve 22 (first stage valves) that in turn control the coupling of one end of a proportional spool valve 24 (second stage valve) to a low pressure rail 36 (typically but not necessarily engine oil) and a still lower pressure vent 37. With both the vent pilot control valve 20 and supply pilot control valve 22 closed, the proportional valve will remain in a fixed position. The proportional valve 24 preferably is a spool valve with a specially shaped spool to block flow when approximately centered, and to provide nonlinearly increasing (at a rate greater than linear) flow area from a high pressure rail 56 to engine valve actuator 28, or to vent the engine valve actuator chamber 26 to vent 39 to allow engine valve return spring 32 to close the engine valve 30, when moved a respective direction from the center position. In the embodiment shown, pressure from the low pressure rail 36 acting on an area at the right end of the proportional valve 24 provides the spool return force, with pressure in line 34 acting on a larger area at the left end of the proportional valve providing the proportional valve actuation force. Alternatively, a spring return could be used.

In usual embodiments, while not shown, the controller will be coupled to sense engine operating conditions and environmental conditions, and control the engine valves in a manner responsive thereto to obtain optimum engine performance. The controller is provided knowledge of the engine valve position at all times by sensor 58, preferably a Hall effect sensor, to allow the controller to respond to deviations of engine valve motion from expected engine valve motion. It is the ability to control engine valve timing and operation in general that makes hydraulic (and other camless) engine valve operating systems attractive.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of an exemplary configuration of a prior art hydraulic valve actuation system.

Figure 2 is a diagram outlining the control strategy utilized to ensure that there is no valve to piston interference.

Figure 3 is a diagram showing the desired minimum and maximum opening timing (Deg) in relation to the piston position.

Figure 4 is a diagram showing the desired minimum and maximum opening flank rate (mm/Deg) in relation to the piston position.

Figure 5 is a diagram showing the desired minimum and maximum height (mm) in relation to the piston position.

Figure 6 is a diagram showing the desired minimum and maximum closing flank rate (mm/Deg) in relation to the piston position.

Figure 7 is a diagram showing the desired minimum and maximum closing timing (Deg) in relation to the piston position.

Figure 8 is another diagram illustrating the aspects of the invention.

Figures showing engine valve trajectories preceding piston position would normally apply to exhaust valve trajectories, while figures showing piston position preceding engine valve trajectories would normally apply to intake valve trajectories for normal engine operation, or to exhaust valve trajectories when in an engine retarding mode. However, various additional technologies such as, by way of example, engine retardation and internal exhaust gas recirculation (IEGR) may call for the opening and closing of the valves at other times, such as the opening of the exhaust valve when the piston is near top dead center on the compression stroke, or the opening of both intake and exhaust valves at the same time.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention methods are good and simple ways of preventing collisions, as they are angle based and do not require a calculation of future piston or valve positions. In that regard, the word "angle" as used herein is used in the context of crankshaft angle, such as, by way of example, from some reference position such as the top dead center position for the respective cylinder of a single or multi-cylinder engine, or for a specific cylinder for a multi-cylinder engine.

In particular, the invention relates to how a camless system will ensure that there are no inadvertent valve to valve and/or valve to piston collisions. Furthermore, this invention will be more successful in accomplishing these goals, and will result in a more robust system than the prior art.

The algorithm used in the preferred embodiment consists of two parts (see Figure 2), and can be described as follows:

First a safe trajectory for the valve is determined. A trajectory may be defined as an engine valve position (lift) versus crankshaft angle. A safe trajectory as used herein may be defined as a trajectory separating acceptable trajectories from unacceptable trajectories, an unacceptable

trajectory being one that may risk or actually cause collision between engine valves or between an engine valve and the engine piston. In some applications, a single predetermined safe trajectory may be used under all operating conditions and environmental conditions. Such a safe trajectory would be permanently stored, such as in a lookup table or equation form or a combination of both, and used to compare with actual engine valve trajectories. If an engine valve ventured into an unacceptable trajectory, the engine valve actuation system could then be commanded to take preventative action, such as to close the valve. If by engine design, valve to valve collisions are not possible, as a minimum, the safe trajectory need only consider crankshaft angle versus engine valve position for crankshaft angles putting the respective engine piston in the general vicinity of top dead center, as engine valve/piston collisions are not possible throughout most of the piston motion without a catastrophic failure such as a broken valve stem. However a safe trajectory might be defined throughout a valve trajectory to provide a warning of a malfunction needing maintenance attention, and/or that if the same malfunction reoccurs near top dead center, could be catastrophic. Also the same or different safe trajectory (properly crankshaft angle re-referenced for both opening and closing crankshaft

angles) could be used for both intake valves and exhaust valves.

In other applications, a single (or one for intake valves and one for exhaust valves) safe trajectory may unnecessarily encroach on desired valve trajectories under certain operating conditions. By way of example, in a hydraulic engine valve actuated system, such as both single stage and two stage systems, a safe trajectory for a cold engine (cold hydraulic fluid) operating at the highest allowable RPM may require a safe trajectory that is too conservative for a properly warmed up engine running at full load at a lower RPM.

Thus in some applications, the applicable safe trajectory may be based on engine operating conditions, which may include but are not necessarily limited to past and current engine speed, acceleration and/or temperature, and environmental conditions, which may include but are not necessarily limited to air temperature, barometric pressure, and/or manifold pressure. In that regard, as used herein, the phrase engine operating conditions and environmental conditions means one or more variables selected from the variables associated with engine operating conditions and environmental conditions. In addition to this data, the past, current and commanded engine load may be used as well.

With respect to the possible use of engine acceleration, an unloaded engine can change engine speed significantly during a single crankshaft rotation. However, rather that calculate a projected engine speed based on present engine speed and acceleration, as one alternative, one might instead use the safe trajectory for the maximum possible engine speed that could be achieved, given its present speed and assuming a no load, maximum power setting condition, provided this does not encroach on desired engine valve trajectories.

If multiple safe trajectories as stored, such as in lookup tables and/or equation form, then a respective one safe trajectory might be used for a range of one or more variables (engine operating conditions, environmental conditions, etc.), or for different ranges of variables, with or without interpolation between safe trajectories. By way of example, one safe trajectory might apply to a range of cold engine, low engine speeds and also apply to a range of warm engine, normal operating speeds.

The safe trajectories may be described by the opening angle, opening flank rate, maximum lift, closing flank rate, closing angle, and the angle where the closing flank decelerates to become the landing rate at which the engine valve seats (see Figure 8). Note that any timing information is prescribed in degrees, not time, and therefore the piston

position and the safe operating conditions determined ahead of time for a particular operating condition are geometrically constrained and will never deviate unless there is a hardware failure. This means that there is no need to ever predict where the piston will be in the future, and that if the desired trajectory is achieved, there will never be valve to piston interference.

In engines wherein valve to valve collisions are possible, then any safe trajectory may need to account for the trajectory of the other possibly colliding valve. This may be done for some engines by merely determining safe trajectories for each valve that do not cross each other. In other engines, this may limit desired valve motion. In such engines, the safe trajectory of one valve might be determined based on the commanded trajectory for the other valve, or based on the actual measured trajectory for the other valve.

Secondly, the best possible set of actuator movements to meet the desired trajectory (see Figures 3 through 7, which also illustrate safe trajectories corresponding to the allowable trajectories closest to the piston), are also determined or calculated based on the above data. The scheduled valve opening and closing angles (deg), valve opening and closing flank rates (mm/deg), the lift (mm), and the seating rate (mm/deg) for the desired valve trajectories

are continuously updated in response to changing conditions. See Figure 2 for a typical desired trajectory for an engine intake valve relative to the piston position illustrated by the curve over the TDC (top dead center) marking.

In addition to lookup tables, or equations, for the desired valve trajectories, there preferably are precompiled lookup tables, or equations, that describe the allowable deviation of the actual valve trajectory from the desired valve trajectory. These allowable deviations are also based on engine position, not time, and therefore are also geometrically constrained by the engine hardware and will not change unless there is a hardware failure.

The system may acquire a memory of known engine and valve responses as a function of various inputs over time. This information may be used to schedule the best possible commands to the control valves (hydraulic system) to meet the desired trajectory. By virtue of controlling the engine valve to an angle based trajectory, the need to predict crankshaft acceleration may be eliminated from the timing of the control events as these events were originally prescribed in degrees and will be issued by the control device on the designated angles.

The control system can monitor, in real time, or in batch manner, the actual trajectory of the engine valve and

compare it to the desired trajectory. If the deviation between the two exceeds the allowable deviation determined as may be described above, corrective action can be taken to try to minimize the deviation. It is also possible that the deviation will be determined to be too large, or not readily correctable, and alternate control actions may be taken, including closing the valve at the earliest possible angle.

There are features that the HVA4 control system uses that also make it inherently more robust to valve to piston interference. Most notable of these is that the system is operated on an angle basis and the timing of various valve events is dictated by angles and possibly small time-offsets from these angles. This eliminates, or reduces, the need for estimating where the system will be on a time basis in the future, but allows events to be triggered at certain angles that can be measured with high accuracy using normal crankshaft angle sensing means.

Thus this invention is an angle based method, and has no need to calculate or predict where in the future the piston or valve will be. Further, this invention does not compare the current valve trajectory with the predicted trajectory of the piston and determine if a collision will occur, but rather prescribes valve trajectories that are safe, and

ensures that they are achieved within certain pre-described limits.

The techniques hereinbefore described are also applicable to other modes of engine operation, such as engine retardation and internal exhaust gas recirculation. In either case, new desired engine valve trajectories will need to be determined, usually dependent on engine operating conditions and environmental conditions. In the case of engine retardation, the exhaust valve or valves are opened at or just after the piston top dead center position at the end of the compression stroke to vent the cylinder and dissipate the energy in the compressed gas. Here valve to piston collisions are possible, much like on the opening of the intake valve or valves on the intake stroke. Now determining an exhaust valve opening safe trajectory (minimum opening angle and maximum opening flank rate) is important. For this purpose, the same safe trajectory for intake valve opening might be used, with or without predetermined modification, or one or more separate safe trajectories might determined for such exhaust valve opening based on engine operating conditions and environmental conditions.

In engines using internal exhaust gas recirculation, both the intake valves and the exhaust valves are open at the same time. Thus in addition to establishing safe

trajectories to avoid valve to piston collisions, in engines with the possibility of valve to valve collisions, separate safe trajectories may be needed for this mode of operation. These may be fixed safe trajectories or may vary with engine operating conditions and environmental conditions. Also the safe trajectory of one valve might be determined based on the commanded trajectory for the other valve, or based on the actual measured trajectory for the other valve, as opposed to being based on its safe trajectory.

There has been described herein certain specific embodiments of the present invention to illustrate some of the multitude of ways the invention may be implemented and practiced. The disclosed embodiments are exemplary only, as the present invention may be practiced in ways too numerous to each be individually disclosed herein. Thus, while certain preferred embodiments of the present invention have been disclosed, it will be obvious to those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.